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640 Gbit/s wavelength conversion

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Abstract: We report on the first demonstration of wavelength conversion of a 640 Gbit/s OOK single channel, single polarisation optical data signal. Error free wavelength conversion is achieved by XPM in 200 m HNLF.

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1. Introduction

The single channel bit rate has continuously increased in deployed optical transmission systems and networks, reaching 10 – 40 Gbit/s in today's commercially available systems. With the appearance of new technologies for optical transmitters and receivers operating near 100 Gbit/s [1], ultra fast signal processing becomes increasingly relevant. At such high bit rates optical signal processing must be considered as a useful supplement to electronic processing. Several signal processing tasks must be addressed in high speed communication systems and networks, including the indispensable wavelength conversion of data signals. Several approaches based on non-linear effects in optical fibres as well as semiconductor structures have been investigated and two wavelength conversion set-ups have been demonstrated up to 320 Gbaud symbol rates [2-3].

In this paper, wavelength conversion by cross-phase modulation (XPM) in highly non-linear fibre (HNLF) is demonstrated for a 640 Gbit/s (640 Gbaud OOK) single channel, single polarisation optical time division multiplexed (OTDM) data signal. This constitutes the highest reported operating speed of a wavelength converter to date. Error free conversion is achieved for all channels, and the best-case penalty in receiver sensitivity is only 2.9 dB compared to the original 640 Gbit/s data signal.

2. Experimental procedure

The experimental set-up is shown in Figure 1. The optical signal is generated by an erbium glass oscillator pulse generating laser (ERGO-PGL) with a pulse repetition rate of 10 GHz and a wavelength of 1557 nm. The pulses are data modulated with a 2^7-1 PRBS in a Mach-Zehnder modulator (MZM) and subsequently multiplexed to 40 Gbit/s in a passive fibre delay 2^7-1 PRBS maintaining multiplexer (MUX). The 40 Gbit/s data pulses are then chirped and spectrally broadened by Self Phase Modulation (SPM) in 400 m of dispersion flattened highly non-linear fibre (DF-HNLF, $\gamma \sim 10 \text{ W}^{-1}\text{km}^{-1}$, dispersion $D = -1.2 \text{ ps/nm/km}$ at 1550 nm and a dispersion slope of $0.003 \text{ ps/nm}^2\text{km}$ – kindly provided by OFS Fitel Denmark). The positive dispersion in the remainder of the transmitter linearly compresses the data pulses to $\sim 560 \text{ fs}$ FWHM in the resulting 640 Gbit/s data signal. The signal is amplified by an EDFA to $\sim 28 \text{ dBm}$ and combined with a $\sim 25 \text{ dBm}$ CW at 1544 nm before injection into 200 m of HNLF ($\gamma \sim 10 \text{ W}^{-1}\text{km}^{-1}$, zero dispersion at 1552 nm and a dispersion slope of $0.018 \text{ ps/nm}^2\text{km}$ – also provided by OFS Fitel Denmark). The CW is phase modulated at 100 MHz to reduce Stimulated Brillouin Scattering (SBS). A counter-propagating 800 mW Raman pump enhances the wavelength conversion in the HNLF. The sidebands on either side of the CW are temporally off-set and it is thus necessary to select only one sideband to form the wavelength converted signal [2]. This is done using a Fibre Bragg Grating (FBG) as a notch filter to suppress the CW and part of one XPM sideband. A 9 nm band pass filter is used to further isolate the converter output, by suppressing the original data signal. The FBG has its centre wavelength at 1545.5 nm, a bandwidth of 3.2 nm and a suppression of $\sim 40 \text{ dB}$. The wavelength converted signal is demultiplexed to the 10 Gbit/s base rate in a non-linear optical loop

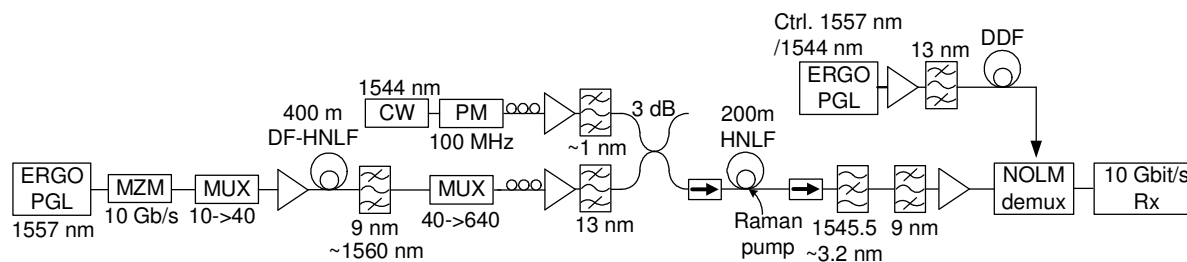


Figure 1. Setup for 640 Gbit/s XPM wavelength conversion.

mirror (NOLM) using 780 fs control pulses generated by adiabatic soliton compression of a 10 GHz pulse train (from a second ERGO PGL) in a dispersion decreasing fibre (DDF). The NOLM comprises 50 m of HNLF with the same fibre parameters as the one used for XPM wavelength conversion. Bit error rate (BER) measurements of the 10 Gbit/s OTDM tributaries are performed to evaluate the system performance.

3. Experimental results

Figure 2, left shows the optical spectrum of the wavelength converted data signal as well as the original 640 Gbit/s signal and the CW probe at the input to the HNLF. In the HNLF, the CW is spectrally broadened through XPM caused by the co-propagating data pulses in the original signal. In this way spectral sidebands are generated on the

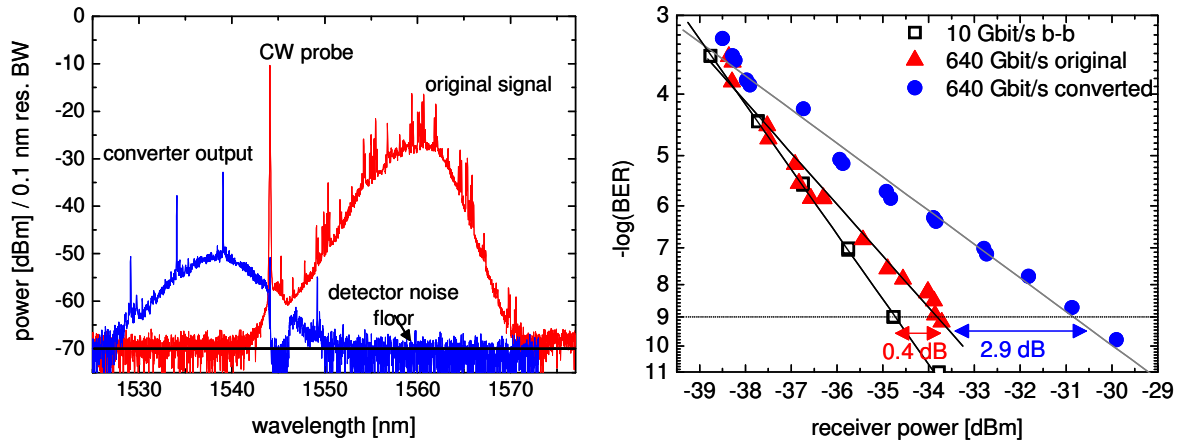


Figure 2. Left: Optical spectrum of the 640 Gbit/s signal before and after wavelength conversion, measured at -20 dB monitor. Right: BER measurements for the converted and original 640 Gbit/s data signals.

CW probe, which reflect the data logic of the original data signal. At the output of the HNLF one of these sidebands is extracted by optical filtering to form the wavelength converted output signal at ~1539 nm. 640 GHz spectral components are clearly visible after conversion, as the wavelength converted signal has adopted the phase properties of the CW probe signal, giving a stable phase relationship between consecutive pulses in the wavelength converted OTDM data signal [4].

Figure 2, right shows BER results for the 640 Gbit/s original data signal and for the wavelength converted signal when demultiplexed down to 10 Gbit/s. The 640 Gbit/s wavelength conversion is successful with error free

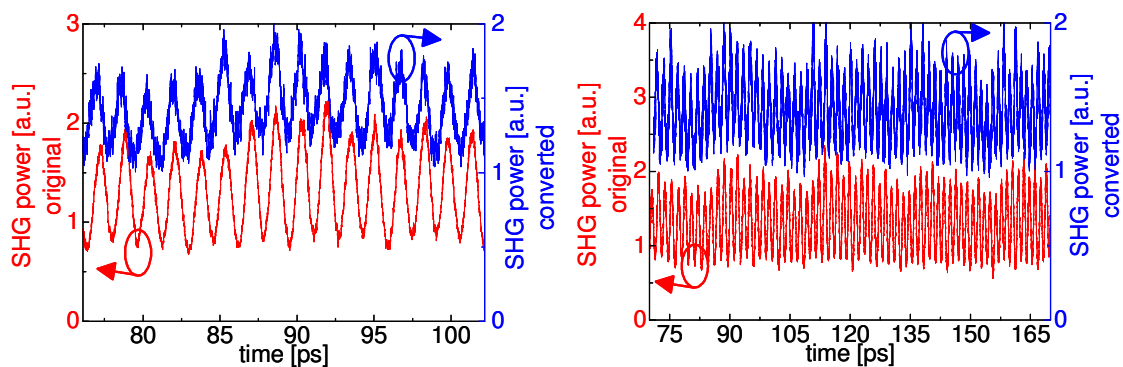


Figure 3. Cross-correlations – Lower traces: 640 Gbit/s original data (FWHM ~560 fs). Upper traces: 640 Gbit/s converted data (FWHM ~660 fs). Left: Zoom in on 16 channels. Right: All 64 channels.

performance. For both the original and the converted 640 Gbit/s signal, error free performance (defined as $\text{BER} < 10^{-9}$) with no sign of an error floor and low penalty compared to the 10 Gbit/s back-to-back (b-b, measured straight out of MZM data modulator) is obtained. In Figure 2, right, a typical channel is shown for the original 640 Gbit/s data signal (channel 64 in figure 4), whereas the BER curve for the converted 640 Gbit/s signal

corresponds to one of the best performing channels in the converted signal (channel 23 in Figure 4), having a conversion penalty of only 2.9 dB. In order to characterise all 64 channels in the OTDM signal, cross-correlations with a 500 fs sampling pulse were performed. In this way pulse amplitudes and pulse widths of each individual channel is investigated. Figure 3 shows cross-correlations of the 640 Gbit/s original data signal together with the converted 640 Gbit/s signal. The average pulse width of the two signals is measured on an auto-correlator to be ~560 fs before conversion and 660 fs after conversion. This increase in pulse width is seen to cause a reduction in contrast in the cross-correlations of the converted signal compared to the original signal. It is expected that the contrast is mainly limited by the width of the sampling pulse, and that actual pulse overlap after conversion is very small. There is a ~1 dB amplitude difference among the original data channels and among the converted channels. Subsequently, all 64 channels are demultiplexed and subject to BER measurements. Figure 4 shows the measured receiver sensitivities (at $\text{BER}=10^{-9}$) of all 64 channels in the converted and the original signals. All 64 converted channels achieve error free operation, clearly demonstrating successful wavelength conversion of the full 640 Gbit/s data signal.

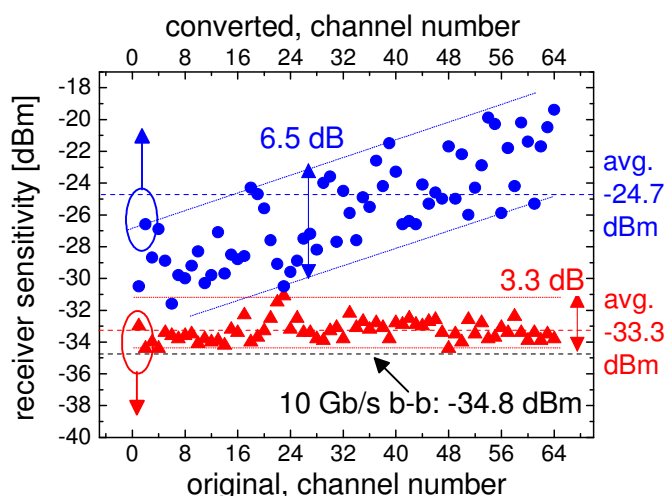


Figure 4. Receiver sensitivity at a BER of 10^{-9} for all OTDM channels in the converted and original 640 Gbit/s data signals.

The original OTDM signal has a good and even performance with an average sensitivity of -33.3 dBm, i.e. an average penalty of only 1.5 dB with respect to the 10 Gbit/s back-to-back. The converted signal has a penalty of only ~3 dB under optimised conditions with respect to the 10 Gbit/s back-to-back. This penalty is mainly believed to be caused by the pulse broadening associated with the wavelength conversion. The pulse broadening is in turn caused by the filter configuration used to extract the output signal from the wavelength converter. There is a ~6.5 dB sensitivity spread due to channel variations in the wavelength converted signal. The increased sensitivity to channel variations in the converted signal is expected to be mainly due to the pulse broadening during conversion. On top of this an ambient drift affected the system for the duration of the measurement, resulting in a slowly deteriorating sensitivity, yielding an average receiver sensitivity of -24.7 dBm. A significantly more stable performance of the converter is thus expected, if the impact of ambient variations can be reduced. Additionally, optimising the filter configuration in the wavelength converter to further reduce pulse broadening, is expected to improve the overall performance of the converter.

4. Conclusion

We demonstrate XPM based wavelength conversion of a 640 Gbit/s data signal. This constitutes the highest bit-rate reported in a wavelength conversion demonstration to date. The wavelength conversion allows error free operation of all tributary channels in the converted signal. Low penalty from wavelength conversion, compared to the input signal, is achieved in an optimised configuration of the converter.

References

- [1] P. Winzer et al, "107-Gb/s optical ETDM transmitter for 100G Ethernet transport," in *Proc. of ECOC*, Th4.1.1 (2005)
- [2] M. Galili et al, "Low-penalty Raman-Assisted XPM Wavelength Conversion at 320 Gb/s," in *Proc. of CLEO US*, CThF4 (2007)
- [3] Y. Liu et al, "Error-Free 320 Gb/s SOA-Based Wavelength Conversion Using Optical Filtering," in *Proc. of OFC*, PDP28 (2006)
- [4] L. Rau et al, "All-optical 160-Gb/s phase reconstructing wavelength conversion using cross-phase modulation (XPM) in dispersion-shifted fiber" *IEEE Photonics Technology Letters*, vol. 16, no. 11, pp. 2520-2522, November 2004.